Abstract patterns and representation: the re-cognition of geometric ornament

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Introduction

I. The Horizon program Knowledge and Culture

This thesis is part of the broader Horizon research program *Knowledge and Culture*, funded by the *Netherlands Organization for Scientific Research* (NWO), in which four domains from the humanities – music, language, visual arts, and poetry – are investigated from the perspective of innate cognitive competences.

Participants in the research program acknowledge that in various fields of cognitive science a paradigm has been developed assuming that humans share with other animals an innate, task-specific, and language independent system allowing them to make mental representations of objects, agents, spatial relationships, number and social interaction. Building on these systems, humans have unique cognitive competences such as the linguistic competence, for instance, which may play a fundamental role in the human capacity to combine the diverse core knowledge systems, allowing humans to increase their cognitive abilities. This may have enabled humans to develop culturally determined knowledge systems including specific languages, sign systems and formal geometry. This conception of human cognition, as partly shared with other species and partly unique, again raises questions about which elements of culture are founded on core knowledge systems, and which belong exclusively to the cultural domain: how do they relate and interact, and how do they form the conditions and constraints of both universals and cultural diversity?[1]

The subproject concerning the visual arts consists of two research programs: one aimed at cognition underlying proportion in architecture, as well as my own project aimed at cognition underlying the recognition and making of geometric decorative patterns. The central assumption that forms the starting point of this part of the research program is that the recognition of geometric decorative patterns is fostered by core knowledge of geometry and number. This assumption is based on cross-cultural empirical research, which shows that adults and children from cultures who lack formal geometry and do not have any words for geometric concepts are still able to recognize

[1] http://www.nwo.nl/onderzoek-en-resultaten/onderzoeksprojecten/i/65/8565.html

certain crucial elements of geometric shapes, for example, parallelism. However, this research also revealed that the same adults and children were unable to perform certain geometrical transformations that required mental rotation, which indicates that the recognition of properties such as parallelism might be a universal feature of geometric knowledge while the capacity to perform a transformation like rotation might not.[2] From the perspective that geometric patterns are regular and repetitive arrangements of geometric shapes, knowledge of number may also play a role in the recognition of repetitive regularity. Experiments indicate that the condition to comprehend a regular arrangement of a number of geometric shapes is present in the form of core knowledge that develops in all humans, regardless of cultural background and education. Two core knowledge systems of number are probably involved, one that allows a subject to exactly discriminate between objects in small quantities of up to four, and another that allows for estimating sizes of large quantities and comparing those in terms of bigger and more.[3] In this dissertation, I will show that the results from core knowledge research resonate with the tradition of anthropological and art historical studies that were aimed at explaining the presence of similar shapes, patterns and design principles found in the decorative arts from cultures around the world.

a. State of research

Research into the underlying cognitive and psychological aspects of geometric decorative patterns dates back to the mid-nineteenth century, and was mainly undertaken by designers of ornament who assumed that certain design principles must have had a common origin.[4] The principle of using relatively simple geometric shapes to create an infinite variation of possible patterns was observed in ornamental patterns

[2] Dehaene, Izard, Pica & Spelke 2006, pp. 381–384.
[3] Hauser & Spelke 2004, pp. 854–855.
[4] It is impossible to provide a complete overview of that research tradition, since the number of studies from art history, cognitive psychology and anthropology dedicated to the cognitive aspects of geometric decorative patterns is vast. Besides, numerous other disciplines have also been involved in the relation between pattern perception, cognition, and the visual arts. Therefore a limited number of the main assumptions and viewpoints will briefly be discussed. In the forthcoming chapters of this thesis the relevant and more specific studies will be discussed in more detail.

from cultures all around the world.[5] These assumptions and observations were supported by substantial encyclopaedia of ornament in which the rich variation of ornaments was categorized.[6] Another assumption was that the use of the same geometric motifs had emerged in these different cultures independently of cross-cultural influence.[7] These kinds of suggestions already pointed towards the possibility of a shared mental make up to explain the generalization.[8] Another possible explanation started from the assumption that geometric patterns exemplified the level of sophistication of a culture's technology. The more skilled its members were, the more complex the patterns generated.[9] As a result of the increasing influence of evolutionary theory, the frequent use of geometric elements could be seen as originating in a human psychological trait that had evolved over time. The tendency towards simplicity in the perception and the making of patterns was assumed to point to the strong survival value of the use of such simple patterns.[10]

Towards the end of the twentieth century, art historical research was increasingly conducted from an explicit global and interdisciplinary perspective. Art historians like John Onians and David Freedberg connected the knowledge obtained from the combined research of art history and the psychology of perception to the relatively new scientific discipline of neuroscience. This allowed for a perspective on visual art that would do justice to both the mental and the physical aspect of making visual patterns, but which could now be studied from a single neuro-scientific paradigm.[11] In this thesis, references will be made more or less to all these different approaches. However, the aim of this thesis is clearly not to provide another categorization of ornament. Nor is it a report of a neuro-scientific approach although visual neuroscience about visual artefacts will be critically discussed in Chapters 2 and 3.

This study is not about preferences and not an empirical study but an argumentative discussion. Some might argue that an empirical approach from the perspective of preferences would have been a logical point of departure. The

[5] Jones 1856, pp. 52–53, 204.
[6] Durant 1986, pp. 10–23.
[7] Riegl in Kain, Castriota & Zerner 1992, pp. 5–7, 16.
[8] Brown 1991, p. 55.
[9] Boas 1927, p. 19.
[10] Gombrich 1979, pp. 5-7.
[11] See for instance Battaglia, Lisanby & Freedberg 2011, pp. 1–6; Onians 2006, pp. 9–21.

widespread use of geometric motifs and patterns has frequently led to the assumption that the regularity and symmetry of such patterns contribute to their aesthetic value. These assumptions were taken to indicate the existence of aesthetic aspects that were independent of cultural context.[12] With regard to the perception of geometric patterns, there is a long tradition of cognitive psychological research which has taken aesthetic preferences as its object of study. As the main advocate of empirical aesthetics, the nineteenth century psychologist Gustav Fechner started to design experiments to empirically determine aesthetic preferences for certain formal properties of art such as the almost mythical "golden ratio".[13] This brought research on the recognition and making of visual patterns to the controlled environment of the laboratory. As such, it has also brought about the important methodological problem of how to control the many variables effective in geometric patterns in a decorative context. The richness of variables involved in decorative contexts does not allow controlling and manipulating the effect of each variable while limiting those variables means losing the decorative context.[14]

Besides the complexity of experiments, I identified another important problem with an emphasis on beauty preferences. I consider this approach insufficient for my study because it appears to obscure an important aspect of geometric decorative patterns. Because similar geometric patterns appear in the decorative contexts of so many different cultures, the assumption is often that they are preferred for their formal characteristics and that they are non-representational.[15] This viewpoint, however, neglects that these patterns are not just applied for the sake of decoration but *do* carry meaning.[16] The potential to carry meaning appears to form a significant part of the human competence to recognize and make decorative patterns.

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[12] Hardonk 1999, pp. 163-167.
[13] Fechner 1876, pp. 484–490.
[14] Hyman 2010, p. 255.
[15] This assumption also underlies a research program by a group of cognitive biologists from the University of Vienna who claim to study the production of decorative patterns. Westphal-Fitch & Fitch 2015, p. 385; Fitch & Westphal-Fitch 2013, p. 140. See also Jacobson & Höfel 2002, pp. 755–766; Leder & Nadal 2014, pp. 443–464; Redies 2014, pp. 468–470; Westphal-Fitch, Oh & Fitch 2013, pp. 13–26.
[16] Boas 1955, pp. 88–97; Gell 1998, pp. 81–83; Washburn & Crowe 2004, p. 260.

b. The research problem

In this dissertation, I will start from the observation that geometric patterns are always used as *representations*. Patterns on mosaic floors can represent ceremonial pathways or cosmic order.[17] Patterns on the baskets of Pueblo Indians represent rivers, animals, or mountains.[18] The linguistic and symbolic contexts in which geometric shapes and patterns are applied suggest that geometric shapes and patterns function exceptionally well as signs and signifiers. This means that in a decorative context the formal properties of geometric patterns are not necessarily or at least not exclusively valued for their assumed aesthetic quality. Symmetrical shapes and patterns might be better suited to function as signs because their symmetrical order is based on innate geometrical concepts that have been selected in the course of evolution, because they facilitate faster recognition, better memorization, and might therefore instantly index a human agent.[19] Perhaps geometric decorative patterns are so widespread because their formal properties contribute to the power to refer to, or represent something else.

Therefore, the recognition and making of geometric decorative patterns will not just be investigated in this thesis from the perspective of the possible relation of the formal properties of patterns with core knowledge of geometry and number. The aims of this thesis are to determine the conditions and constraints of cognitive competences, to recognize and make use of the formal properties that constitute geometric decorative patterns; and to understand the extent to which these properties endow geometric decorative patterns with the potential to refer to, or to represent something else. From that perspective, core knowledge of number and geometry should be regarded as integral parts of those conditions.

c. Research method

To arrive at such an understanding, I aim to develop an argument based on both the study of artefacts and the analysis of experimental, theoretical and historical sources

[17] Claussen 2002, p. 319; De Blauw 1987, p. 351; Foster 1991, pp. 4– 6.
[18] Boas 1955, pp. 91, 96, 102; Mason 1988, pp. 178–212.
[19] See for example Changizi, Zhang, Ye & Shimojo 2006, pp. 117–139.

from different fields of science such as cognitive science, semiotics, anthropology, and art history. The main findings from those disciplines will be analyzed and compared to arrive at a formulation of the possible conditions and constraints for the recognition and making of geometric patterns. It is, therefore, in a sense that this thesis could be considered a record of interdisciplinary research. As a consequence, it deals with the problem of different levels of explanation and a different use of the concepts involved.[20] One of the main problems is how to arrive at an adequate use of the concepts. This is a nontrivial problem within an interdisciplinary approach, because different scholars and scientists define specific terms differently depending on the theoretical framework in which phenomena, events, evidence and data are interpreted. Interdisciplinary research, therefore, requires a crystal-clear terminology to ensure that the meaning of the various terms and definitions is kept consistent.[21]

II. Core concepts

Before explaining how the argument in this thesis will unfold, I will therefore begin by defining some of the main concepts as clearly as possible.

a. Cognition

Cognition is regarded as the faculty or set of faculties that enables humans to acquire knowledge. In the past decades, different views about how knowledge is organized in the brain have developed in the cognitive sciences. Hypotheses have been formulated about the extent to which some of that knowledge, or the structures facilitating knowledge, could already be present at birth. On the basis of experimental research,

[20] Scholars can for instance approach geometric patterns from the perspective of how these patterns are visibly applied to concrete objects such as vases, baskets, and walls. See for instance Grabar 1992, pp. 119–154. Cognitive scientists can approach patterns as mental concepts emerging from cognitive competences with regard to spatial relationships between distinguishable visual elements. See for instance Diamand & Carey 1990, pp. 345–368. Visual neuroscientists study the neural substrate underlying cognitive and perceptual competences. See for instance Haushofer, Baker, Livingstone & Kanwisher 2008, pp. 753–762. Although these levels are obviously related, they cannot be reduced to one and another. Looking at a decorated vase depends on neural activity but neural activity does not capture the full extent of that experience.

[21] Schoot 1998, p. 280.

one school of psychologists assume that the brain is functionally organized as a set of modules within which each module is dedicated to a specific cognitive task. These modules are relatively independent from other modules, and from the brain's central processing unit.[22]

Core knowledge theory holds that cultural skills are based on a set of innate psychological and neuronal mechanisms, which emerge early in human development and are the building blocks of human cognitive skills. Each system deals with specific entities such as agents, objects, and places in the spatial environment. They each use their own 'representations' to answer specific 'questions' about the world. Core knowledge modules are also relatively encapsulated; they only receive a limited portion of information from the sensory system and they only transfer a limited portion of information to the output system of the organism. Finally, they are relatively autonomous and therefore not susceptible to explicit beliefs or goals from the subject.[23] That is, they operate on a subconscious level.

Core knowledge enables a clear functional description of the cognitive competences underlying the recognition of number, certain invariant properties of shape and the recognition of agents. However, it is also founded on a specific scientific and theoretical framework with which researchers approach the workings of human cognition in relation to the brain, namely an understanding of the human brain as modular. From that perspective, it might be relevant to discuss the extent to which this conception is tenable when compared to other scientific and theoretical paradigms such as connectionist views.[24] This would require a comparative study on cognitive theories and that is not the scope of this thesis.

Therefore, I take as my starting point the concrete appearance of geometric decorative patterns. By identifying the ways in which they function within cultural contexts, I will arrive at an analysis of the underlying competences that would be required to recognize and make such patterns, and at a description of the conditions and the constraints that the underlying competences seem to obey. I will therefore

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[22] Fodor 1983, pp. 1–38.
[23] Hauser & Spelke 2004, p. 853.
[24] About this issue see for instance Garson, James, "Connectionism", *The Stanford encyclopedia of philosophy* (Winter 2016 Edition), Edward N. Zalta (ed.), URL = <https://plato.stanford.edu/archives/win2016/entries/connectionism/>

make use of the term cognitive competence, and use core knowledge whenever I explicitly refer to the research of the group of cognitive psychologists working within that paradigm, or to the literal meaning in the sense of knowledge that is probably innate and fundamental for acquired knowledge.

b. Pattern

The definition of *pattern* used in this thesis holds that a pattern is a regular and repetitive ordering of (a set of) identical elements along one or more (imaginable) visual axes.[25] Its regularity distinguishes the pattern from a series. Although a series of cups on a table top, or a row of books on a bookshelf can be regarded as a distinguishable ordering as well, the cups and books in a series are not strictly ordered along regular intervals, and are not necessarily separated from each other by equal spaces. Also, a series is not necessarily ordered along an axis. A pattern is thus a specific kind of ordering of one or more different kinds of elements that participate in the ordering. A dotted line, for example, is a pattern of elements (dots) along a single horizontal axis with equal spaces separating the dots; a checkerboard is a pattern of elements of the same size (squares) along horizontal and vertical axes.

c. Decoration

The adjective 'decorative' is often associated with aspects of beauty and appreciation but should not be limited to such connotations, and should not be regarded as a purpose in itself. I assume *decorative* to relate to the process, the specific way in which an artist applies coherence in the patterns of motifs onto artefacts, which endow these artefacts with a quality that makes them attractive.[26]

[25] Washburn & Crowe 1988, p. 52.
[26] Vickers 1998, pp. 344–345.

d. Ornament

The result of the decorative process is an *ornament*. A geometric pattern is an ornament insofar as it imparts the decorated with a distinctive character.[27] As a result, the decorated acquires the potential to function as an intermediary between the object and a subject because it points to the object, as it were: a vase with geometric patterns is no longer just a vase; it becomes distinctive.[28]

e. Representation

In the context of the visual arts, representations are often understood as those pictures that visualize 'natural' objects and bodies by means of imitating or resembling in paint, or any other medium, some of the essential formal properties of the objects and bodies represented. From that perspective, a landscape or a portrait is obviously representational. This conception of representation, however, is too limited and problematic for several reasons that will be discussed in Chapter 3. Therefore I will use

[27] The term 'ornament' has its origins in the Latin nouns *ornatus* and *ornamentum*. Within the decorative arts ornament is often defined as adornment but defining ornament exclusively as adornment neglects the term's complex history and the specific historical and cultural circumstances under which the concept of ornament started to play a role within the visual arts. Even though 'adornment' and 'embellishment' are part of its significance Caroline van Eck underscores that for the Romans, *ornatus* in general meant distinction and excellence, which denotes the condition of being well equipped with good qualities in order to deal with situations of any kind. To this context *ornatus* also owns its significance as something marked with honour. It is not unimportant to mention that *ornatus* had a military connotation in the sense of being fully equipped as a soldier; it furthermore denoted military honour and distinctive behaviour. In rhetoric *ornatus* meant that an orator had the excellence and the resources available with which he could draw the attention of the audience and persuade them for his cause. The difference between both nouns is that *ornatus* refers more to the act of decorating or embellishing persons and buildings, the act of giving honour to someone, and endowing something or someone with grace and honour, while *ornamentum* refers for instance to the equipment, to the object to be decorated, to the circumstance that causes reason to endow someone with honour. See Glare 1982, p. 1270. Quintilian VIII.8.3.2. Eck 2007, p. 25. & Vickers 1998, p. 314. Vickers here draws on the remarks made by Kennedy. See Kennedy 1969, p. 81.

[28] The definitions of the concepts 'decorative' and 'ornament' will obviously raise more questions than that of 'pattern'. This is because they are rooted in concepts from classical rhetoric and therefore have a long and culturally charged history. A neutral definition is probably impossible. Used in the meaning of embellishment 'decorative' and 'ornament' are often also applied to the arts from non-Western cultures. I do not principally reject that use because despite their classical origin both concepts appear to be the most appropriate for use with regard to arts and crafts in general. I do think though it is important to realize that this meaning of embellishment is also not neutral and must also be situated within its Western European context. Decoration and ornament conceived as a means with which to endow an object with special status seems to be the most neutral conception possible.

a definition of representation that captures the broad use in which images *function* as representations. In this definition, *representation* denotes the power to make something immediately present to the mind of a subject.[29] From that perspective, representation by means of imitating and resembling is one of a number of ways in which to accomplish this. Referring is another.[30] The condition for representation is that there is something that represents and something that is represented. That which represents is called a 'sign' and signs can make bodies, objects and phenomena present in different ways, which will be discussed more extensively in Chapter 3. Geometric decorative patterns can function as signs or contain signs that refer to something else and by means of that make that something present to a subject.

III. Structure of the argument

The assumption underlying the main argument of this thesis is that geometric patterns are referential and therefore have the potential to bring to mind a particular referent, i.e. geometric patterns have the potential to be representational. Considering this, the widespread presence of geometric patterns should not only be understood from the assumed underlying cognitive competences that condition the recognition and making of the formal properties of these patterns, but also from the assumption that the relative simplicity of form of the pattern's motifs makes them extremely suitable as signifiers. Regardless of whom or what they refer to or make present, geometric patterns are selected for such representational purposes in different cultures around the world.[31] If only the cognitive competences allowing the recognition and reproduction of the formal properties of patterns were studied, the above point would be missed, and this thesis would reduce to a dissertation about pattern-recognition in general. However, this thesis focuses on geometric patterns within a particular cultural context, namely a decorative one. Therefore, my point of departure is that within different

[29] Derived from the Latin *repraesentare* in the meaning of the power to make something present to the mind, to make something manifest, or to bring something to the present. *Repraesentare* also denotes the representation in the arts in the sense of a portrait, an imitation or a resemblance but that is part of the broader meaning of the ability to make present. Imitation and portrayal could be regarded as one of the many ways in which something can be made present to the mind. See Glare 1982, p. 1621.
[30] Burge 2010, pp. 31–33.
[31] Scharfstein 2008, pp. 343–367.

cultures, the application of geometrical decorative patterns depends on formal properties and design principles that are partly determined by preferences selected by the mechanisms of the human cognitive and perceptual systems, but are also partly culturally determined. This cultural determination becomes specifically clear when it concerns the representational content with which decorative patterns are endowed. Within each cultural context, geometric patterns can refer to or represent objects, bodies and ideas, even although their actual content differs from culture to culture. This suggests there must be a competence that allows humans to recognize artefacts as representational, and that allows them to endow artefacts with representational content. Therefore the argument is that a competence to represent presupposed by the making and recognizing of visual patterns, is a universal disposition; while its manifestation, for instance, in the form of geometric decorative patterns applied to artefacts, is culturally determined and embedded.

a. Geometric decorative patterns

To identify the conditions for recognizing and making geometric decorative patterns, the geometric pattern has to be dissected into its main constitutive elements to determine what a subject would need to understand each building block of a geometric decorative pattern. This implies a distinction between the ordering, the element ordered, and the direction in which the ordering unfolds.

A pattern is a regular and repetitive ordering of elements along one or more axes. The repetition can unfold in one dimension along a single horizontal or vertical axis, or in two dimensions along both horizontal and vertical axes. The ability to recognize and understand patterns must therefore involve a competence to imagine a recursive ordering extending in one or more dimensions in space along one or more axes. This requires a competence to individuate one element from another, to understand those as belonging to a quantity, to understand the ratio between those elements, and to understand geometric properties such as length and direction.

In a decorative context, the recursive element of a pattern is referred to as the motif.[32] Geometric motifs are distinguishable from naturalistic and stylized motifs as abstract motifs made of straight and curved lines whose shapes do not seem to have formal resemblances with natural bodies and objects. Geometric decorative patterns are thus regular and repetitive orderings of geometric shapes. To recognize geometric motifs implies the competence to recognize shapes. Shape recognition is based on the recognition of the invariant geometric properties of shapes; the nature and number of lines and angles are the most defining visual features of shapes. Lines are the building blocks of geometric shapes and the competence to understand line is at least a precondition to recognize and make geometric patterns.[33]

As the motif of a pattern, geometric shapes can be repeated and rotated, which can result in either mirror or glide symmetry. To understand rotation and mirroring requires the ability to recognize shapes as uniform under the circumstance that these shapes are orientated differently in space, occupy different spatial positions, or differ in size. This requires the competence to perform a mental rotation of shapes.[34]

The conditions to be met in order to recognize and make geometric patterns thus assumes the competence to recognize *shape*, the competence to individuate shapes and distinguish one from another, as well as the competence to recognize the regular arrangement of elements along a straight or curved axes in one or more dimensions, i.e. the recognition of spatial dimensions such as length and direction.

b. Geometry, number, and shape recognition

The necessary conditions for the competence to recognize and make geometric decorative patterns can be described in psychological terms. According to core knowledge theory, core knowledge is present at birth as a set of dispositions that will develop as the infant grows.[35] These form the cognitive foundations for the acquisition

[32] Trilling 2001, p. 36.
[33] Sayim & Cavanagh 2011, pp. 1–4.
[34] Dehaene, Izard, Pica & Spelke 2006, pp. 381–384.
[35] Core knowledge theory departs from the assumption that core knowledge is non-species specific and thus shared with other animals. However, in this thesis the recognition and making of geometric patterns in humans is central and therefore I will not extensively discuss core knowledge in animals.

of culturally informed knowledge.[36] Cross-cultural experiments in which adults and children from North America and the Amazonian Indian tribe the Mundurukú participated, showed that both groups were able to recognize and use basic mental concepts with regard to geometry, number, and shape recognition, regardless of formal training in geometry.[37]

In core knowledge theory, two systems of number are identified. Used in combination they condition the competence to comprehend a regular ordering of individual elements occupying specific spatial positions and condition the competence to regard this ordering of elements as a quantity.

With regard to the recognition of geometric shapes, core knowledge theory proposes that the understanding of the concepts of angle and length are innate, while that of mirror-symmetry relies on further cultural development of geometric knowledge. Mirror-symmetry is a frequently used important feature of decorative patterns; this could indicate that visual features that are cognitively harder to grasp, increase the pattern's attractiveness.

Research from visual neuroscience indicates that the recognition of shapes is a step-by-step process in which different networks of neurons process visual features of an increasingly complex nature with each step in the process. The recognition of lines is at the basis of this process. The comprehension of line should therefore condition the geometric concepts of angle and length because the recognition of line, the competence to recognize its length and direction, and the competence to comprehend the possible intersection of lines with other lines, allows the recognition of angle, one of the defining features of shapes.

Core knowledge of number and geometry therefore provide a functional description at the psychological level of the aforementioned cognitive competences, which can be substantiated by neuroscientific research.

[36] See for an overview Spelke & Kinzler 2007.
[37] Izard & Spelke 2009, pp. 213–248.

c. Geometric patterns as representations

Even although abstract motifs such as geometric shapes are often regarded as non-representational, geometric motifs do function as representations of referents. Empirical experiments from the core knowledge research program provide many insights into the underlying cognitive competences that allow the recognition of the formal properties of patterns, but it cannot explain how geometric shapes and patterns can function as a representation. The conditions and constraints of the competence to consider an element *a* to refer to or stand for another element *b*, should therefore be identified and described using other disciplines. The discipline of semiotics has shown that for an artefact to be a representation, it functions as a sign, or it includes signs that can represent something else or refer to something else.

According to Nelson Goodman and Charles Sanders Peirce there are four ways in which geometric patterns can function as signs. These are identified as icon, index, symbol and exemplification.[38] Art historical and anthropological studies show that geometric decorative patterns predominantly function as an index, but can function as a symbol as well albeit in a special way. This is possible because from the recognition of the ordering of visual patterns, i.e. the recognition of the specific formal properties of visual patterns, humans infer that these patterns were made intentionally and carry meaning.[39]

The competences for number, geometry, and shape recognition are constitutive for the recognition and making of the formal properties of patterns. In addition, humans are able to infer intentionality from the inner structure of visual patterns. This means that the conditions and constraints for the competences to recognize and make geometric decorative patterns also condition the possibility for making that inference. The question is how that works. This question cannot be answered by experiments. Patterns are too layered to dissect into single variables that could be put to a test, and humans probably do not infer intentionality from a single feature of a pattern but from

[38] Atkin, Albert, "Peirce's Theory of Signs", *The Stanford encyclopedia of philosophy* (Summer 2013 Edition), Edward N. Zalta (ed.), URL = https://plato.stanford.edu/archives/sum2013/entries/peirce-semiotics/; Goodman 1968, pp. 3–43.
[39] Gell 1998, pp. 73–95. Grabar 1992, pp. 119–154.

the entire ordering.[40] In other words, an experimental situation is probably not representative for a decorative context, while a sufficiently rich decorative context likely contains too many variables. Besides, using pictures in an experiment with regard to representation poses the methodological problem that any picture of a geometric decorative pattern is already a representation, while the question what makes patterns representational concerns the conditions and constraints of the process by means of which the pattern acquires the potential to represent.[41]

d. How abstract patterns become representations

Another body of knowledge is needed to understand the recognition and making of decorative patterns as a step-by-step process in which all the variables involved are critically assessed. This body of knowledge can be found in the history of art. This history contains many theories, originally aimed at artists, which show how visual artefacts are created by means of constructing a web of points and lines. Since they describe the process of production, they can also shed light on how and at which point such constellations of lines acquire the potential to refer to or represent something other than itself. The most illustrative is the theory of linear perspective. It is generally conceived as a typical product of the European history of art within which it offered a theoretical and practical foundation for painters of 'naturalist' pictures. This is true to a certain degree. As a technique of representation, linear perspective is indeed embedded within the cultural and historical context of fifteenth-century Florence.

A critical reading of Leon Battista Alberti's (1404–1472) treatise *De pictura* will make it clear that its relevance reaches beyond the representation of 'naturalist' pictures. The principles on which linear perspective is based have emerged from the practice of applying forms and patterns to surfaces of objects by means of points and lines, as well

[40] See for instance Gell 1998, pp. 73–95.

[41] In the early eighties this problem was more widely acknowledged. In the foreword of Margaret A. Hagen's *The perception of pictures vol. II*, Rudolf Arnheim signalled unawareness amongst many experimental psychologists when it comes to the methodological problems using representational pictures as experimental stimulus. See Arnheim 1980, p. xii. In the same volume Marx Wartofsky for instance argued that human perception is determined by the different modes of representations humans use and therefore the study on visual perception cannot be limited to the human visual system and the workings of optics but should concern these modes of representation as well. See Wartofsky 1980, pp. 131–133.

as by defining the outlines of plots of land; practices that precede its theorization as geometry. The value of Alberti's treatise lies in its practical approach of geometry with which Alberti demonstrated how space and objects are defined on the flat surface by means of points and lines.[42] Alberti identified the point as the painter's essential element, and showed how the point should be seen as a marking from which a line, conceptually understood as a sequence of points, can emerge. The conception of a point as a marking allows one to conceptualize each element as distinct from another, an individualization that can also be applied to the lines created between individual points. This enables one to conceive the construction of the formal elements of pictures as a process, by means of which humans create constellations of lines that can be identified as a new individual entity, for example, as geometrical shapes and geometric patterns. When, by means of a few geometrical operations, the painter draws a checkerboard floor receding into space, the painter has used the basic elements of points and lines to create a constellation of lines in the form of a grid from which the painter constitutes a trapezoid, which within a certain context represents something which a trapezoid is not: a floor receding into space.[43] This process shows that linear perspectival representations are indebted to the competence for making geometric patterns. In other words, naturalistic images have abstract patterns as their foundation. This means that the cognitive competences underlying the making of the simplest two-dimensional patterns precondition the competence to make more complex visual patterns such as a linear perspectival image of a city.

Under certain conditions, shapes and patterns evoke a competence allowing humans to consider a figure *a* to refer to or stand for a figure *b*. Humans make that inference in response to certain formal properties of visual patterns. The process that leads to such inferences is ultimately conditional for visual patterns to be recognized as representations.

[42] In this thesis I will mainly quote from the English translations by Sinisgalli 2011, & Grayson 2004, as well as the Dutch translation by Hermans, annotated and commented by Eck & Zwijnenberg 2011.
[43] Alberti*, De pictura*, $ 2–3.

e. A material perspective on the recognition and making of patterns

The concrete manifestation of this competence as meaningful visual patterns in the form of cross-hatchings on pots, maze patterns on floors, abstract shapes on baskets, and patterns on textiles is present in many different cultures. The constraints that are imposed on the kind of inferences drawn are culturally determined; a trapezoid might not necessarily represent a receding floor in each culture. Even from village to village the meaning of a zigzag pattern can differ.[44] But meaning it has!

Each of the above-mentioned practices is an example of how humans exploit their cognitive competences using their body to manipulate materials with specific techniques to make artefacts and patterns. In each practice the making of patterns serves a specific function, for instance, drawing attention to an object or marking a border between one space and another. In addition, an approach is needed which makes it possible to understand the making of geometric decorative patterns not just from the context of cognition but as something humans do. The German architect and art historian Gottfried Semper (1803–1879) was the first to introduce such a perspective.

Semper showed how making patterns came naturally with the craft of weaving; a process that initially involved connecting branches or threads made of natural fibres into a cloth: a cloth that could function as a surface to encircle a certain space.[45] Such as line is the basic material for the painter; line in the form of the thread is the basic material for the weaver.[46] The weaver weaves different individual threads into patterns constituting pieces of cloth, just like the painter, as Alberti phrased it, weaves a web of lines to create a surface on the picture plane.[47] The concept of line is therefore not only a mental one, but has a material and physical aspect. Semper showed how all these aspects are fundamental for the competence to make and understand representations. By means of the way in which the weaver rhythmically manipulates material using his body, the mental concept of line is transferred onto the visual artefact where it

[44] Mason 1988, pp. 178–212.
[45] Semper 1851, p. 57.
[46] Mallgrave 1996, p. 270.
[47] Grayson 2004, p. 38.

becomes its manifestation. As such, the pattern of lines in the form of a weave becomes an index of its maker and of the maker's body and mind being unified in the manufacturing process.

When surfaces were later made of other material, the weaves of the earliest manmade constructions were imitated in these materials, a process that Semper observed on the Assyrian stone panels at the British Museum. These patterns had now literally become the representations of earlier motifs, patterns, techniques and practices. This brought Semper to the insight that visual patterns always index previous patterns or patterns derived from other techniques and as such are part of a history of evolution of motifs and patterns.[48]

Semper's perspective represents a challenge to rethink numerical and geometrical cognition as related to the human body, to materiality and technology, and to the history of motifs and patterns that were the result of the physical manipulation of materials; perhaps even as (partially) shaped by this history. Therefore Semper's connection between cognitive competence and physical condition might clarify exactly how the physical manipulation of materials fosters the integration of numerical cognition and cognition of geometry. This perspective seems to have gotten lost in the controlled lab experiments of present-day cognitive science: probably because it is very hard to investigate this by means of experiments because of the many variables involved in these processes that were highlighted by Semper.

IV. Towards a new body of knowledge

It should be acknowledged that Alberti's and Semper's theories were formed in different times against different historical and cultural backgrounds. This might have been the reason that although they have been extensively discussed in various scholarly contexts and perspectives, they have never been explicitly related to each other. At the risk of being anachronistic, I will show that there is a remarkable similarity between Alberti's concept of creating surfaces on the flat panel by means of weaving a web of lines, and Semper's notion of woven cloths as the primordial surfaces with which

[48] Semper 1851, pp. 59–60.

spaces were divided. From the perspective of an investigation into the cognitive competences underlying the recognition and making of geometric patterns as representations, both theories thus seem to point to the same cognitive process underlying the making of patterns. Therefore they can provide a basis for a new body of knowledge with which to approach the underlying competences that are needed to recognize and make geometric decorative patterns and with which to enrich cognitive research.

Alberti departed from the most basic building blocks of a practical geometry with which painters start the process of creation: the point and the line. Because the purpose of linear perspective was to achieve a naturalistic representation, Alberti had to meticulously show how the process leading to such a representation should unfold. It starts by drawing a few basic lines from a few basic points. However, at some point and for some reason, constellations of lines start to be interpreted as a representation of a spatial body or object. Four lines forming a trapezoid can be interpreted as a receding floor; four lines forming a parallelogram can be interpreted as the side of an open book or the side of a gable roof. Cultural background is likely to be a decisive element in whether one is actually able to see the trapezoid as a floor or the parallelogram as a side of a roof. In other cultures subjects may recognize other things in those shapes, but what is important is the finding that simple geometric shapes elicit the suggestion of a reference to something else. This therefore suggests a cognitive competence to recognize in one thing a reference to, or a representation of, another. Every system of representation is founded upon that competence. That is what the theory of linear perspective implicitly shows and for that reason Alberti's treatise can be considered as one about representation in general. It touches upon the same interests as those of later psychologists of perception. What is difficult to show in psychological experiments is demonstrated within *De pictura*: recognizing and making representational patterns is a mental *process* and during this process constellations of points and lines at some point become susceptible for reference and representation.

In order to further understand how this works one will have to look beyond representations in the form of drawings. Semper was one of the first to situate the emergence of patterns within the earliest practices of the weaving of mats with which in

early cultures humans were able to enclose a space. For Semper these enclosures were the origin of monumental architecture and the related decorative arts. Semper's idea about the practice of braiding together natural fibres, i.e. threads, as one of the precursors of weaving, allows for the opportunity to consider one of the fundamental components of shapes and patterns, the line, as detached from the practice of drawing, as a mental concept that humans are able to apply in different formal and material contexts. Because Semper situated the emergence of architecture in the earliest crafts, he made it possible to arrive at what could be considered an anthropological view on the development of patterns and motifs in those crafts, and on how they functioned throughout history as indices of earlier motifs. The importance of Semper's theory is that it enables a consideration of the recognition and making of geometric decorative patterns as activities that are not just matters of perception and cognition. While Alberti's emphasis on the process that makes constellations of lines into representations points to a cognitive competence to represent, Semper's insights can be used to consider this cognitive competence as part of the reciprocal process of body and mind, with which humans, by means of the rhythmical labour of the body and the use of tools, are able to manipulate materials into artefacts that are part of cultural contexts in which these artefacts have the potential to refer to, or represent, bodies, objects, ideas and phenomena that are external to the artefact itself.